Path Loss

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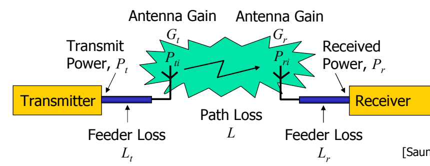
ECE 4823

Definition of Path Loss

- Path loss includes all of the lossy effects associated with distance and the interaction of the propagating wave with the objects in the environment between the antennas



[Saunders,`99]

Motivation

- Need path loss to determine range of operation (using a link budget)
- This module considers two cases,
  - Free space
  - Flat earth

Received Power

- The power appearing at the receiver input terminals is

$$P_r = \frac{P_t G_t G_r}{L_t L L_r}$$

- All gains G and losses L are expressed as power ratios and the powers are in Watts

dBm and dBW

- Powers may also be expressed in
  - dBm, the number of dB the power exceeds 1 milliwatt
  - dBW, the number of dB the power exceeds 1 Watt.

$$P_r \text{ (in dBm)} = 10\log_{10} \frac{P_r \text{ (in Watts)}}{10^{-3}\, Watts}$$

EIRP

- The effective isotropic radiated power (EIRP) is

$$P_{ti} = \frac{P_t G_t}{L_t}$$

- The effective isotropic *received* power is

$$P_{ri} = \frac{P_r L_r}{G_r}$$

Antenna Gains

- Antenna gain may be expressed in dBi or dBd
  - dBi: maximum radiated power relative to an isotropic antenna
  - dBd: maximum radiated power relative to a half-wave dipole antenna
    - A half-wave dipole has a peak gain of 2.15 dBi

Path Loss

- The path loss is the ratio of the EIRP to the effective isotropic received power

$$L = \frac{P_{ti}}{P_{ri}}$$

- Path loss is independent of system parameters except for the antenna radiation pattern
  - The pattern determines which parts of the environment are illuminated

Free-Space Path Loss

- In the far-field of the transmit antenna, the free-space path loss is given by

$$L = \frac{(4\pi)^2 d^2}{\lambda^2}$$

- The far-field is any distance d from the antenna, such that

$$d >> \frac{2D^2}{\lambda}, \quad d >> D, \quad \text{and } d >> \lambda$$

where D is the largest dimension of the antenna.

Power and Electric Field

- The peak power flux density in free space:

$$P_d = \frac{EIRP}{4\pi d^2} = \frac{P_t G_t}{L_t 4\pi d^2} = \frac{|E|^2}{\eta}$$

$$= \frac{|E|^2}{120\pi\Omega} = \frac{|E|^2}{377\Omega}$$

where $|E|$ = envelope of the electric field in V/m

- This holds in the neighborhood (but far field) of transmitters on towers

Effective Aperture

- Antenna gain may be expressed in terms of effective aperture, A_e

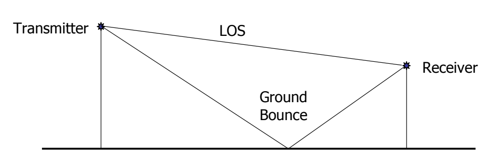
$$G = \frac{4\pi A_e}{\lambda^2}$$

- The aperture intercepts the power flux density

$$P_{ri} = P_d A_e$$

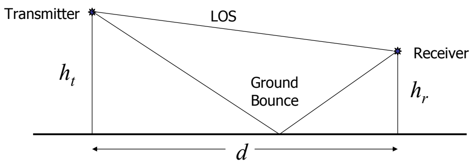
Flat Earth (2-Ray) Model

- If there is a line-of-sight (LOS) path, then the second strongest path is the ground bounce



Typical Relative Dimensions

- $d >> h_t,\ \ d >> h_r$ for a typical mobile communications geometry



Field Near Transmitter

- Let the field at a distance d_o in the neighborhood of, but also in the far field of, the transmit antenna be $E(d_o,t)$, and its envelope be E_o
- Assuming the transmitter is high enough,

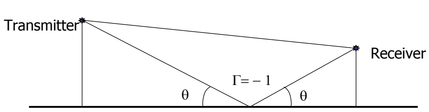
$$\frac{P_t G_t}{L_t 4\pi d_o^{\ 2}} = \frac{E_o^{\ 2}}{120\pi}$$

- The field at some other distance $d>d_o$ is

$$E(d,t) = \frac{E_o d_o}{d}\cos\left(\omega_c\left[t-\frac{d}{c}\right]\right)$$

Low Grazing Angle

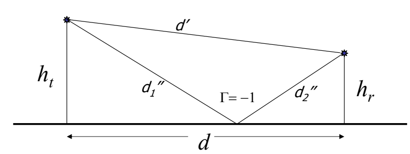
- At such a low (grazing) angle of incidence (θ=a few degrees), the reflection coefficient is -1 for horizontal polarization



Field at Receiver

- The direct and bounce paths add coherently

$$E_{TOT}(d,t) = E(d',t) - E(d'',t)$$
$$d'' = d_1'' + d_2''$$



Long Baseline Effects

- Since d is so large, $\frac{1}{d'} \approx \frac{1}{d''} \approx \frac{1}{d}$

$$E(d,t) = \frac{E_o d_o}{d'}\mathrm{Re}\left\{e^{j\omega_c\left[t-\frac{d'}{c}\right]}\right\} - \frac{E_o d_o}{d''}\mathrm{Re}\left\{e^{j\omega_c\left[t-\frac{d''}{c}\right]}\right\}$$

$$\approx \frac{E_o d_o}{d}\mathrm{Re}\left\{e^{j\omega_c\left[t-\frac{d'}{c}\right]} - e^{j\omega_c\left[t-\frac{d''}{c}\right]}\right\}$$

$$= \frac{E_o d_o}{d}\mathrm{Re}\left\{e^{j\omega_c\left[t-\frac{d''}{c}\right]}\left(e^{j\omega_c\left[\frac{d''-d'}{c}\right]} - 1\right)\right\}$$

A Trick

- Pull an exponential with half the phase out to make a sine

$$\frac{E_o d_o}{d}\mathrm{Re}\left\{e^{j\omega_c\left[t-\frac{d''}{c}\right]} e^{j\omega_c\left[\frac{d''-d'}{2c}\right]} 2j\left(\frac{e^{j\omega_c\left[\frac{d''-d'}{2c}\right]} - e^{-j\omega_c\left[\frac{d''-d'}{2c}\right]}}{2j}\right)\right\}$$

$$= \frac{2E_o d_o}{d}\mathrm{Re}\left\{e^{j\omega_c\left[t-\frac{d''}{c}\right]} e^{j\omega_c\left[\frac{d''-d'}{2c}\right]} j\sin\left(\omega_c\left[\frac{d''-d'}{2c}\right]\right)\right\}$$

Field Envelope at Receiver

- Recall d”>d’
- The envelope of the field is then

$$|E_{TOT}| = \frac{2E_o d_o}{d} \sin\left(\omega_c \left[\frac{d'' - d'}{2c}\right]\right)$$

- Can show that $d'' - d' \approx \frac{2h_t h_r}{d}$, and

$$\sin\left(\omega_c \left[\frac{d'' - d'}{2c}\right]\right) \approx \omega_c \left[\frac{d'' - d'}{2c}\right]$$

Power Received

- Making the substitutions yields

$$|E_{TOT}| = \frac{2E_o d_o}{d} \frac{2\pi h_t h_r}{\lambda d}$$

- The power received is

$$P_{ri} = P_d A_e = \left(\frac{|E_{TOT}|^2}{120\pi}\right)\left(\frac{G_r \lambda^2}{4\pi}\right)$$

Flat Earth Path Loss

- Recalling $\frac{P_t G_t}{L_t 4\pi d_o^{\,2}} = \frac{E_o^{\,2}}{120\pi}$ gives

$$P_{ri} = \frac{P_t G_t G_r h_t^2 h_r^2}{L_t d^4}$$

- The flat earth path loss is therefore

$$L = \frac{d^4}{h_t^2 h_r^2}$$

Summary

- Free space path loss depends only on distance and wavelength, and falls off as $1/d^2$
- Flat earth path loss
  - depends also on the antenna heights, and falls off as $1/d^4$
  - Has a pretty good fit to urban and suburban environments, even though it is an idealization, derived only for horizontal polarization
- The power of d is called the path loss exponent
- For mobile comm, this exponent is typically between 3.5 and 4

References

- [Saunders,`99] Simon R. Saunders, *Antennas and Propagation for Wireless Communication Systems*, John Wiley and Sons, LTD, 1999.
- [Rapp, ’96] T.S. Rappaport, *Wireless Communications*, Prentice Hall, 1996
- [Lee, ’98] W.C.Y. Lee, *Mobile Communications Engineering*, McGraw-Hill, 1998